



Concrete Storage: Update on the German concrete TES program

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Development of Concrete TES

- Concept development and study phase 1988 - 1992
- Lab scale development and testing at DLR and ZSW till 1994

During 1995-1998 no success to receive funds by FWP5

“Reanimation” of activities in year 2000

- **WESPE Project 11.2001 - 12.2003
funded by German Ministry of Environment BMU**
- **Storage for CSP part of DLR program Solar Research**



WESPE

Further Development of Thermal Energy Storage based on Solid Materials

Overall Objective

- Energy storage technology for parabolic trough plants with specific costs $< 20 \text{ € / kWh}$
- Transfer to commercial state in 5 years
- Validation of storage material and design
- Design, manufacturing and testing of a 0,5 MWh storage module

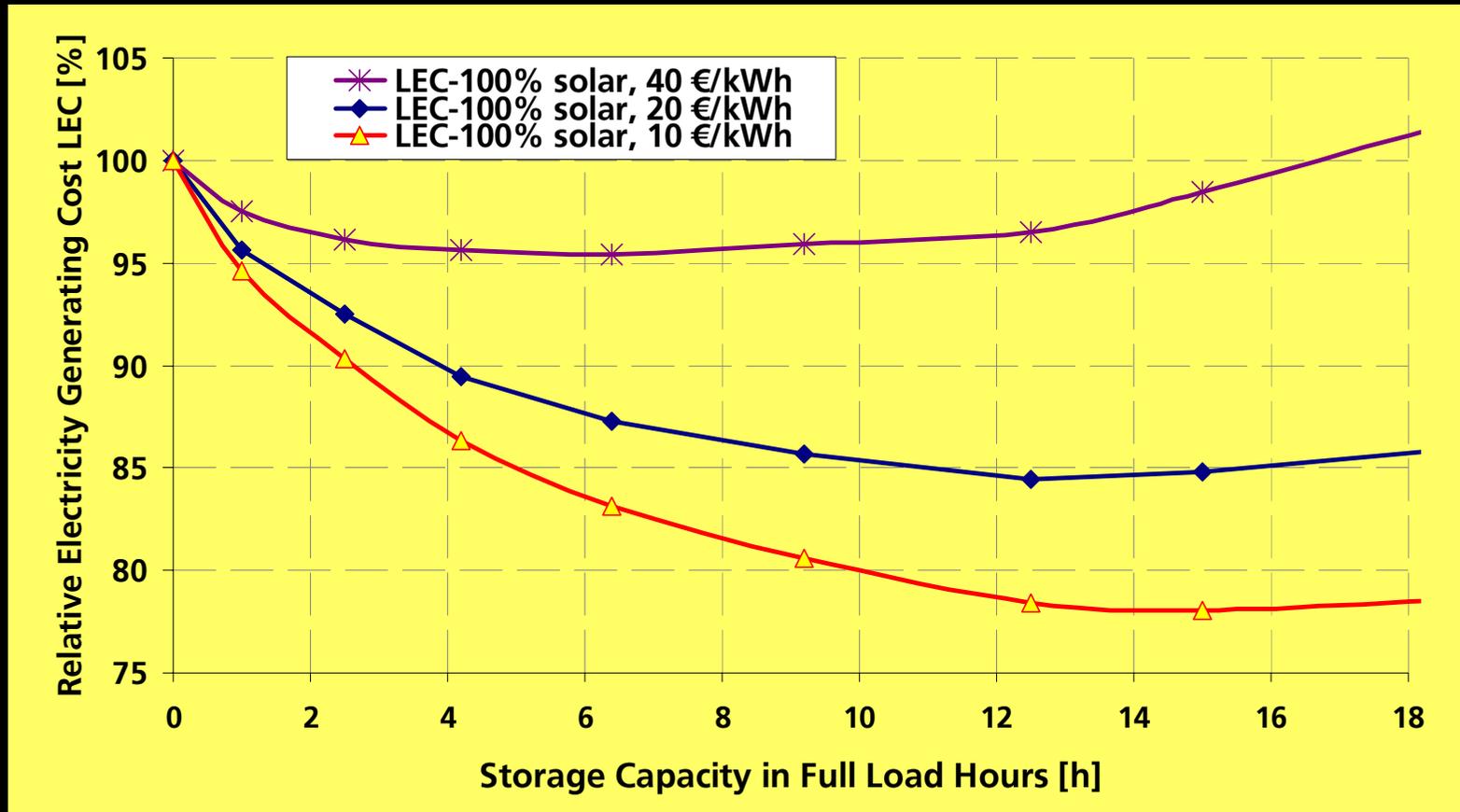
Target of WEPE (for end 2003)

Contractor:	DLR, integrated into PARASOL consortium
Sub-contractors	Siempelkamp, C-Tech Ceramics



Impact of storage size and storage costs on LEC

50 MW_{el} solar only - Mediterranean site





Major Research and Development Areas

Storage medium

- ⇒ thermal conductivity
- ⇒ spec. heat capacity + density
- ⇒ long term thermal cycling resistance
- ⇒ thermal expansion + mechanical stability
- ⇒ material cost

Heat exchanger design

- ⇒ geometric dimensions and arrangement
- ⇒ pressure losses
- ⇒ manufacturing aspects and costs



Development of Innovative Sensible Storage Material

		Sand	Basalt	High Temp.	Castable
		Concrete	Concrete	Concrete	Ceramics
Density ρ	kg/m ³	2050	2340	2400	3400
Spez. Wärme c_p	J/kgK	940	920	970	940
$\rho \times c_p$	kJ/m ³ K	1927	2153	2328	2970
Therm. conductivity λ	W/mK	1,1	1,4	1,2	1,4
Therm. expans. coeff.	10 ⁻⁵ /K	8-10	10	10,5	12,3
Costs	€/m ³	100	112	137	270
	€/t	49	48	57	80



Development of Innovative Sensible Storage Material

Castable ceramic storage material:

- binder including Al_2O_3
- aggregates: mainly iron oxides

High temperature concrete:

- cement binder
- aggregates: mainly iron oxides



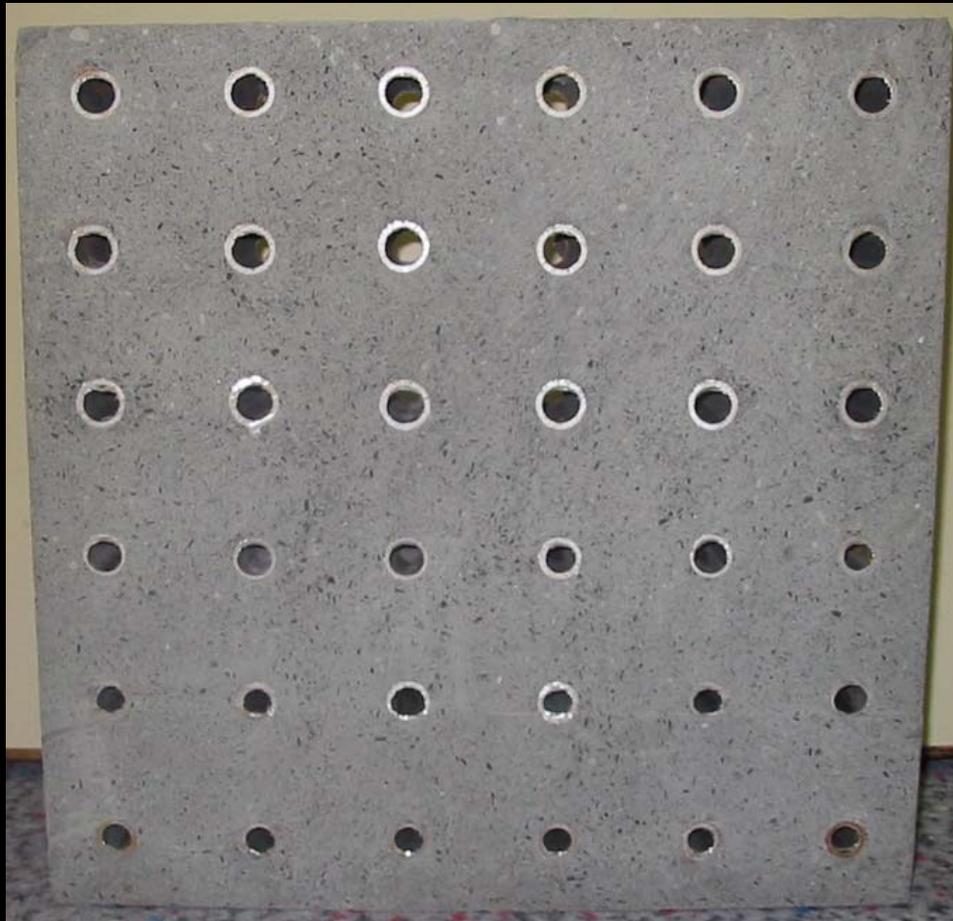


Test block of concrete with and without sheeting





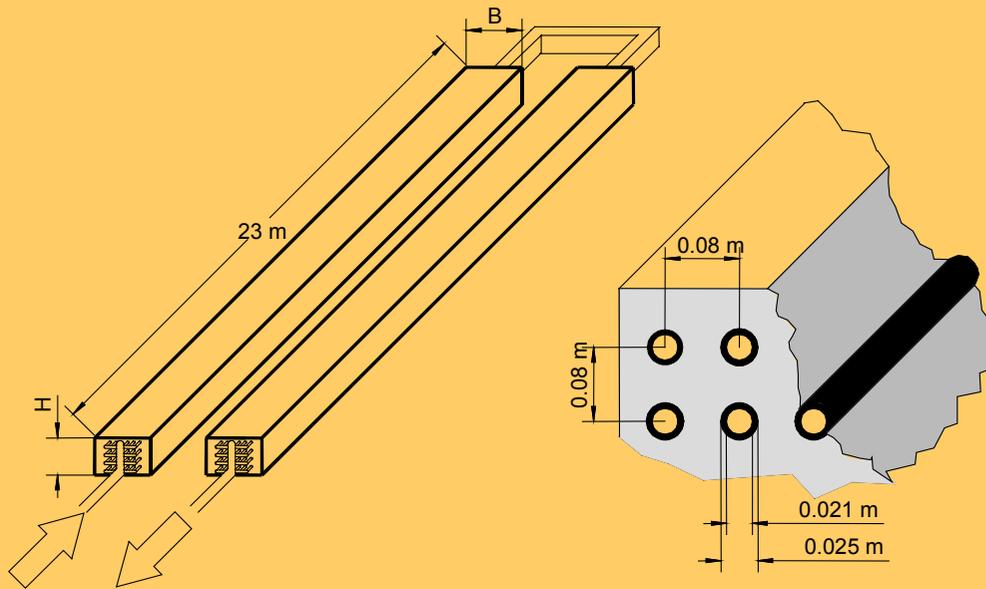
Cut trough concrete storage block



- **Excellent contact between HTF tubes and concrete**
- **Equal/homogeneous distribution of solid phases in the concrete**
- **Low porosity**



Test Storage Module Design

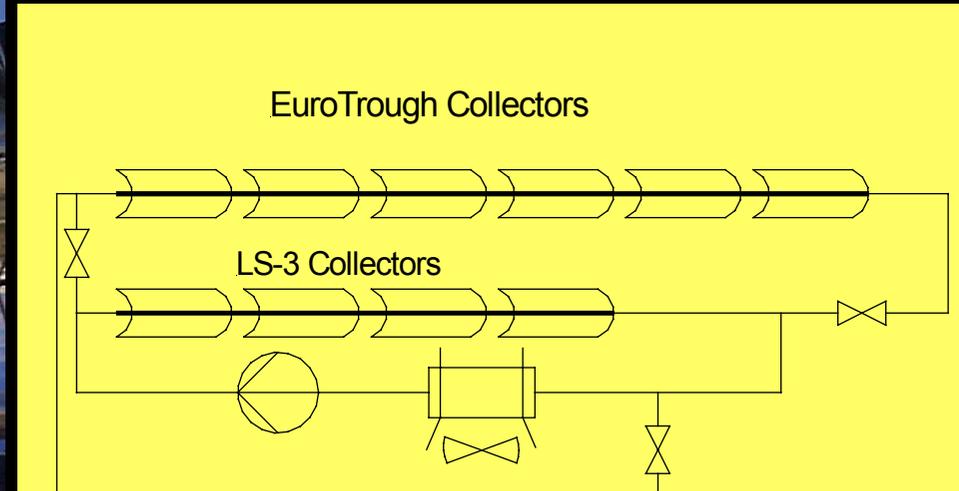


Design parameters

T_{in} , charging:	390°C
T_{in} , discharging:	300°C
Charging/discharging time:	1 h
HTF flow velocity:	0,5 m/s
Length L:	2*23 m
Width B:	0,480 m
Height H:	0,480 m
Volume total:	10,6 m ³
Volumen storage material:	9,8 m ³
Number of pipes:	36
d_i :	0,021 m
d_a :	0,025 m
$\Delta x = \Delta y =$	0,080 m
spec. heat transfer area:	13,3 m ² /m ³



Parabolic Trough Test Loop at PSA



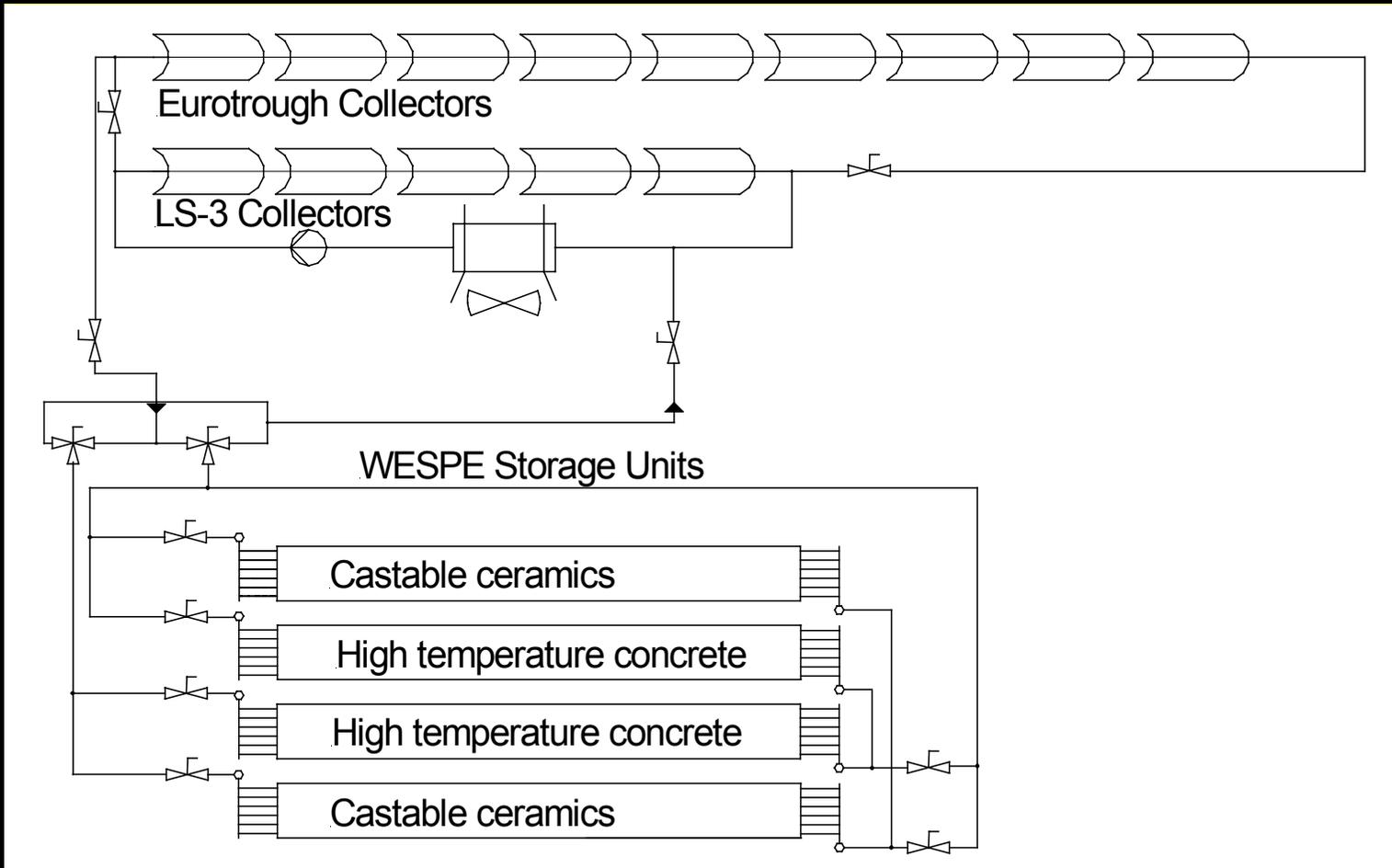
Collectors: 50 m LS-3
75 m EuroTrough

Max. thermal power: 480 kW

HTF: synthetic Oil



WESPE storage module integration into test loop

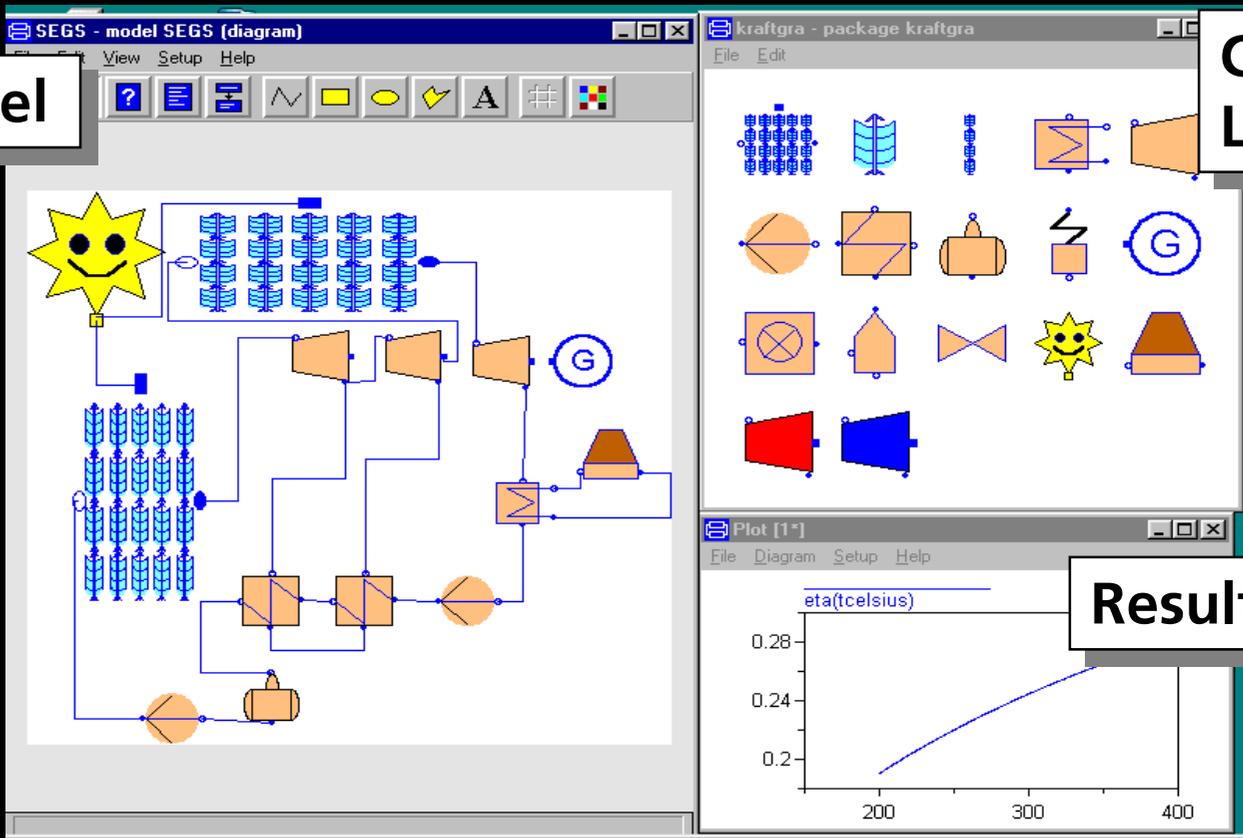




Screenshot of MODELICA simulation tool for transient systems

Model

Component-Library



Result-Plot

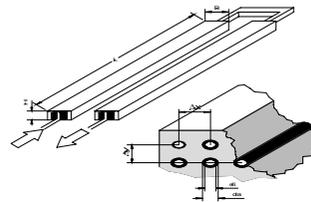
The screenshot displays the MODELICA simulation environment. The main window shows a model diagram titled 'SEGS - model SEGS (diagram)' with a toolbar and a complex schematic of a power system. The schematic includes a sun icon representing a solar collector, multiple heat exchangers (represented by blue vertical rectangles), pumps (orange trapezoids), and a generator (circle with 'G'). A component library window titled 'kraftgra - package kraftgra' is open on the right, showing a grid of various components like heat exchangers, pumps, and solar collectors. A plot window titled 'Plot [1*]' is also visible, showing a graph of efficiency η (labeled as 'eta(tcelsius)') versus temperature. The y-axis ranges from 0.2 to 0.28, and the x-axis ranges from 200 to 400. The plot shows a blue curve that increases from approximately 0.18 at 200 to 0.26 at 400.



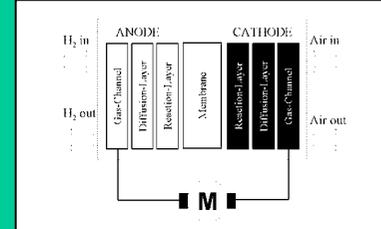
Model Libraries for Modelica



Solar
TechThermo



Storage
TechThermo



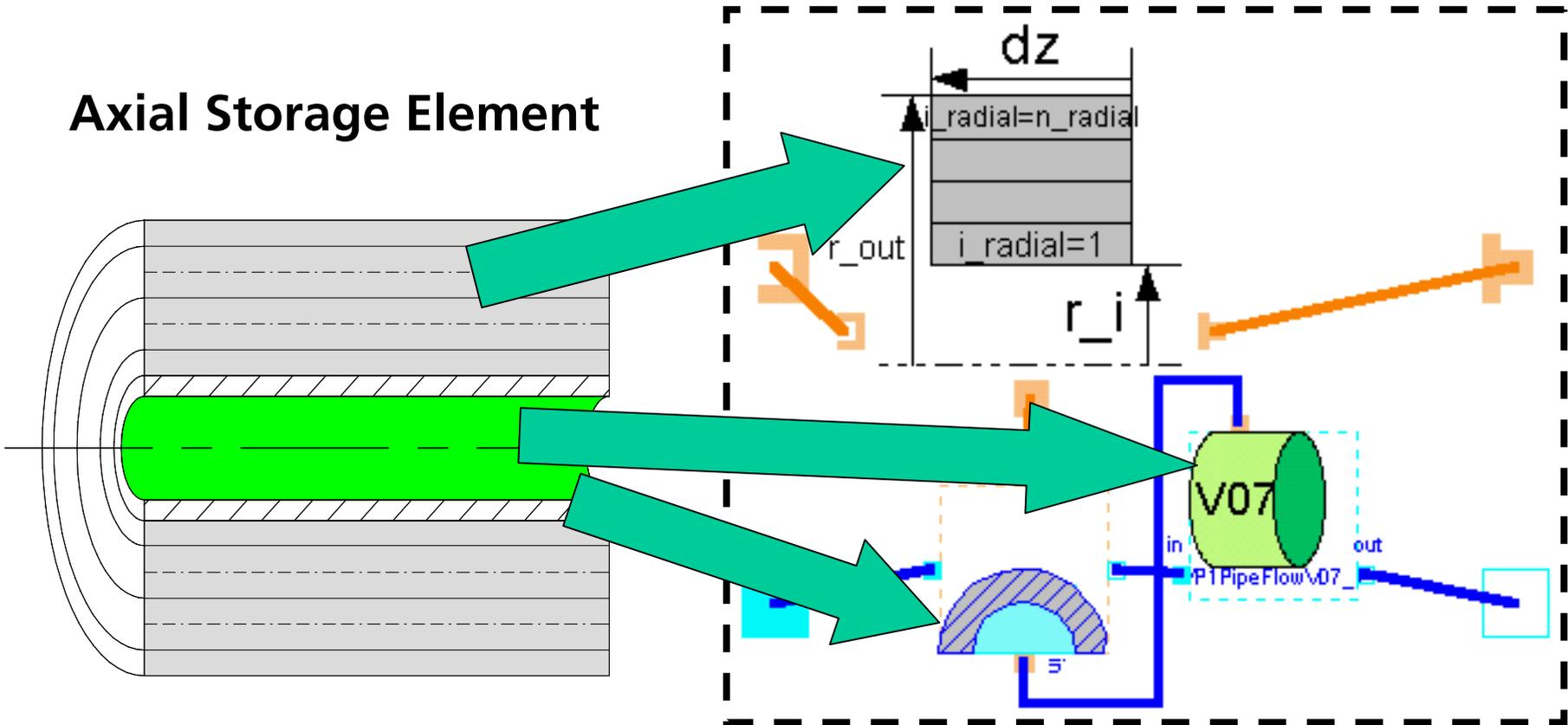
Fuel Cell
TechThermo

TechThermo
Base Library
Technical Thermodynamics



Storage Model in Storage TechThermo

Axial Storage Element



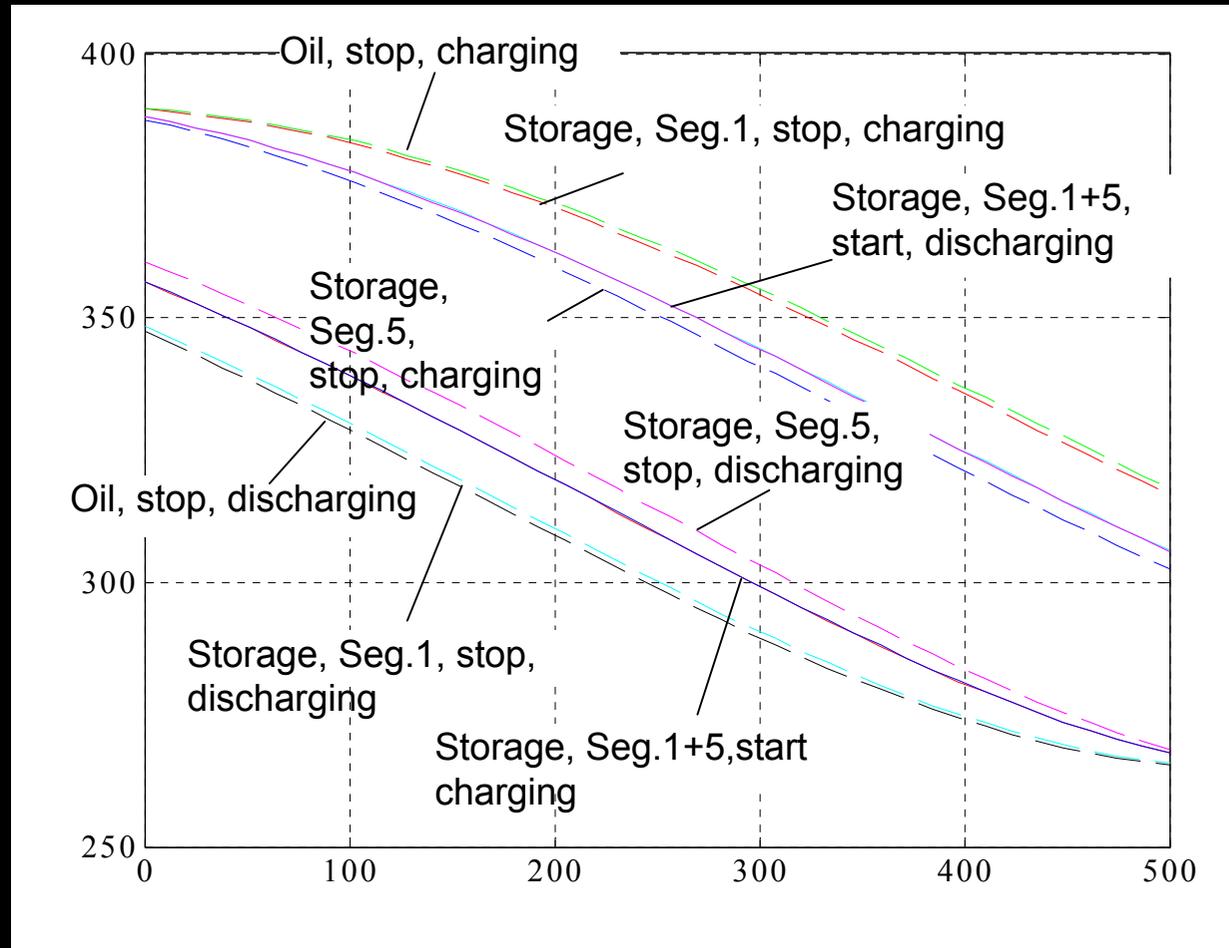


Calculated Temperature Profile beginning and end of charging and discharging, respectively

**3 h / 450 MWh_t storage
with castable ceramics for
50 MW_{el} plant**

**density ceramics 3.400 kg/m³
spec. heat 900 J/kgK
therm. Conduct. 1.40 W/mK**

**length 500 m
tube diameter 0.02 m
wall thickness 0.001 m**





Preliminary Cost Estimation

3 h / 450 MWh_t storage with castable ceramics for 50 MW_{el} plant

Results (± 20 %)

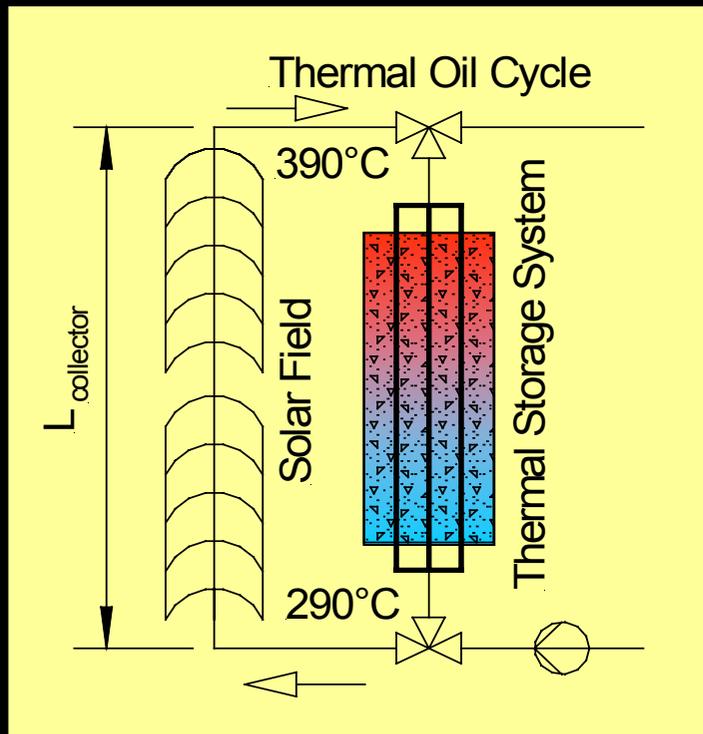
Assumptions	
Tubes for heat exchanger array	1600 € / 1000 kg
Factor for HX manufacturing, extension and header,	150 %
HTF oil	2300 € / 1000 kg
Storage material	80 € / 1000 kg
Insolation	120 € / m ²

Total heat exchanger array tubes	3.9 Mio €
extension, header, manufacturing	1.56 Mio €
	2.34 Mio €
Storage material	3.4 Mio €
HTF oil	1.0 Mio €
Insolation material	0.1 Mio €
Total cost	8.4Mio €
Specific cost	18.7 € / kWh

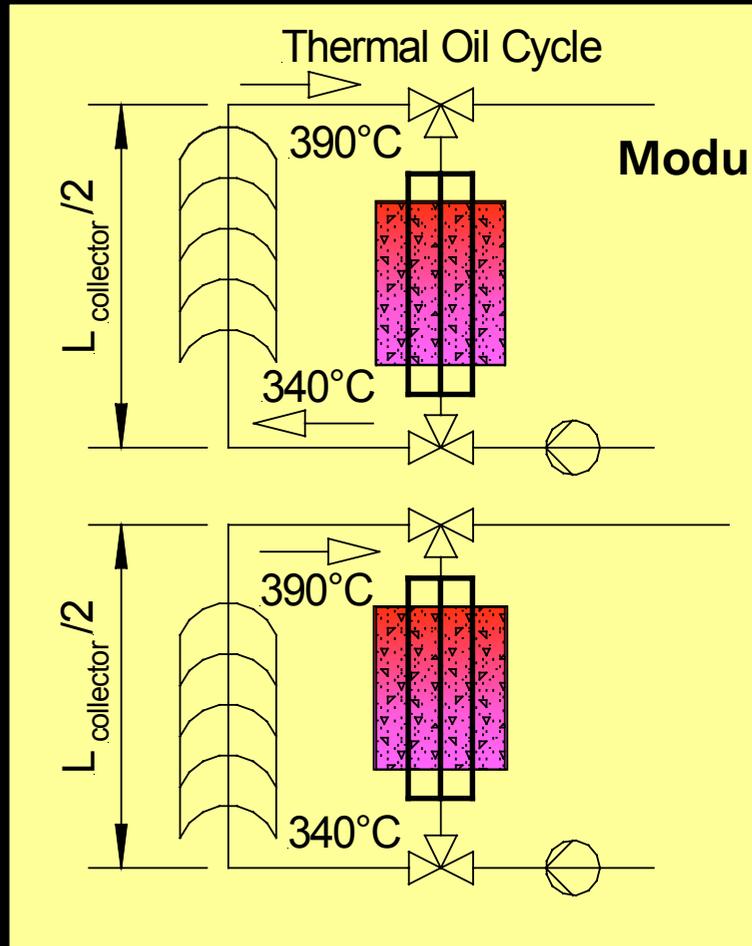


Alternative Integration Concepts

**Single unit
basic concept**



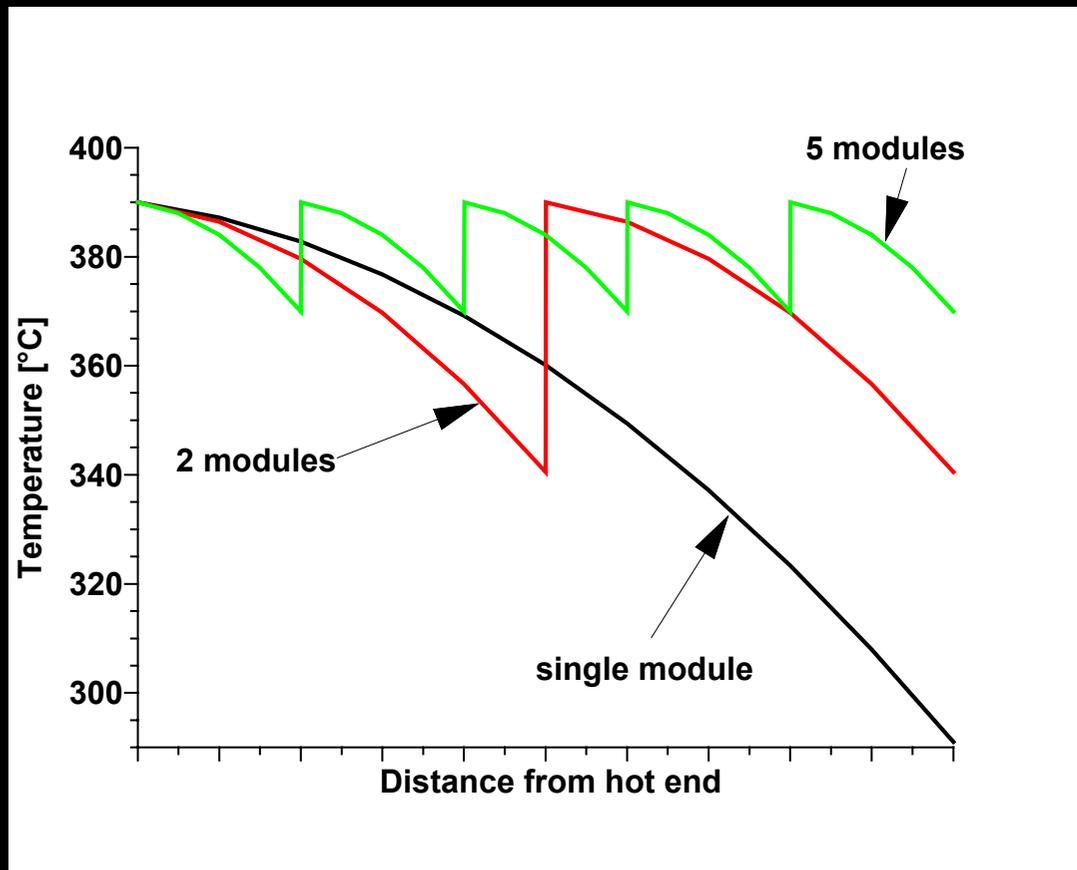
Modular charging concept



**Maximum collector
temperature
determines
acceptable storage
exit temperature**



Temperature Profile for the Modular Charging Approach



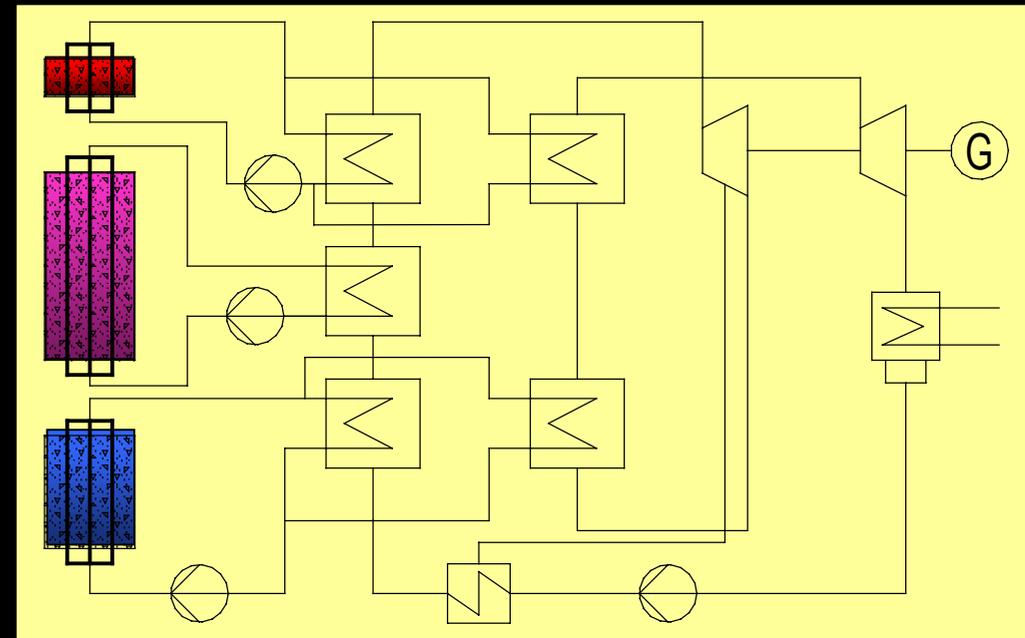
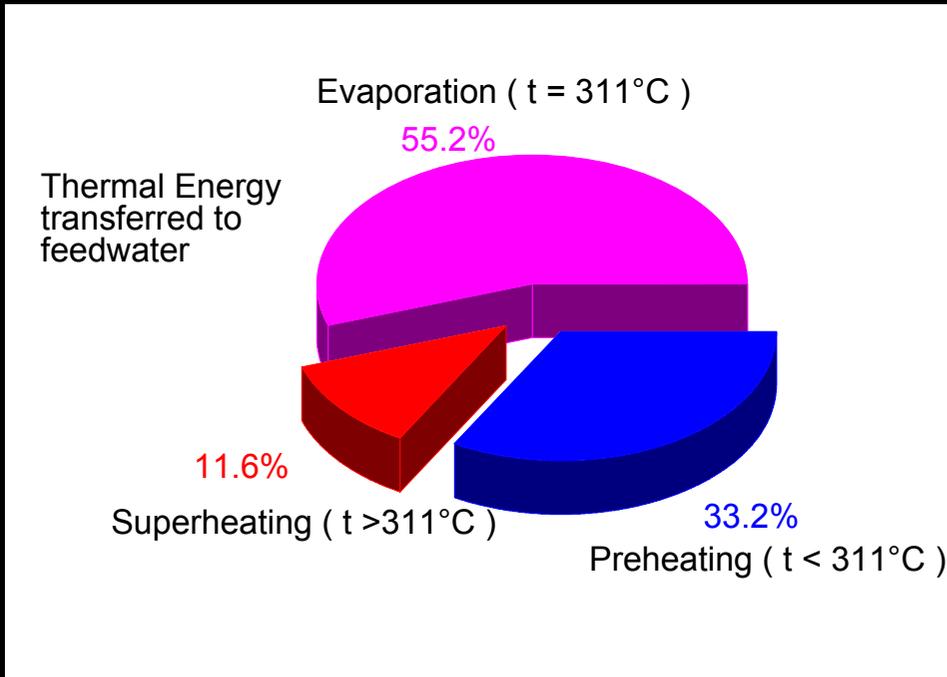
Temperature profile of the storage material after end of charging

Average storage temperature increases with increasing number of modules



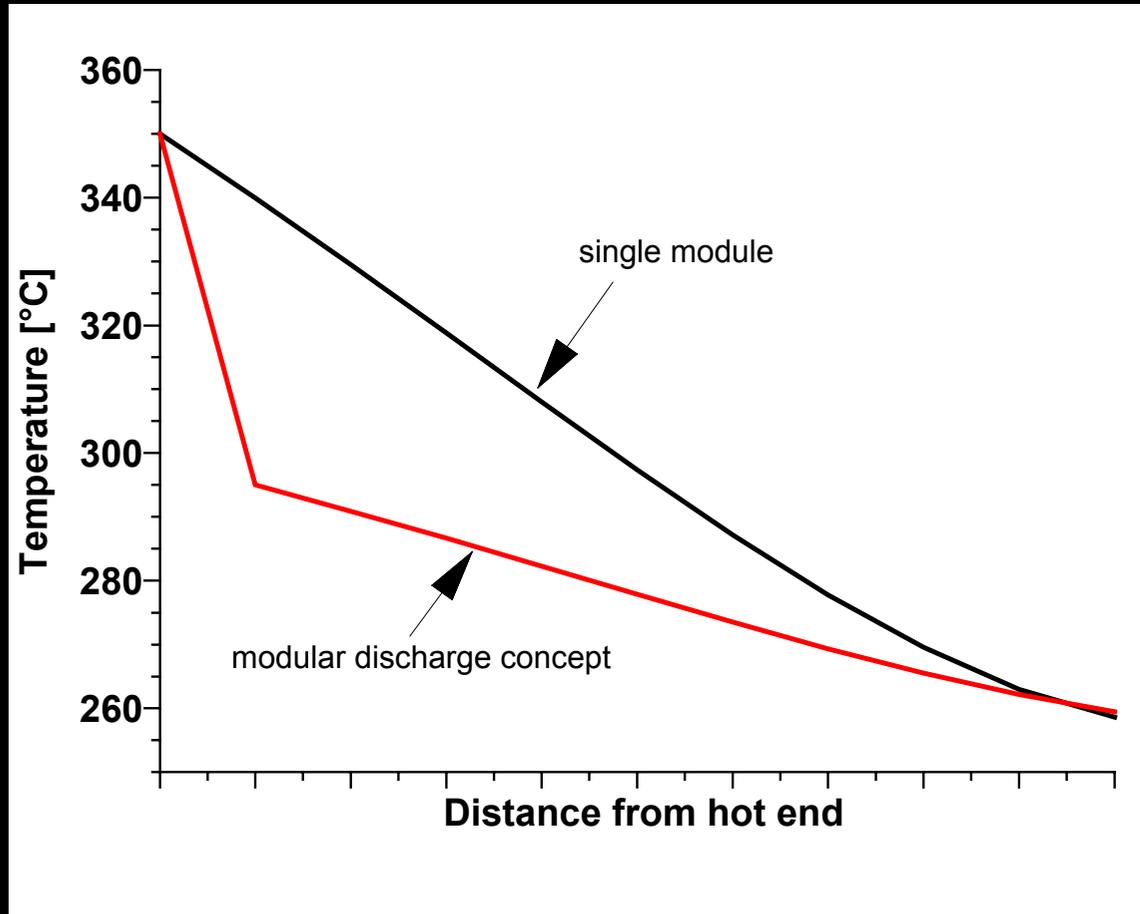
Modular Discharge Concept

Adaptation of the storage system to characteristics of Rankine cycle





Temperature Profile for the Modular Discharging Approach

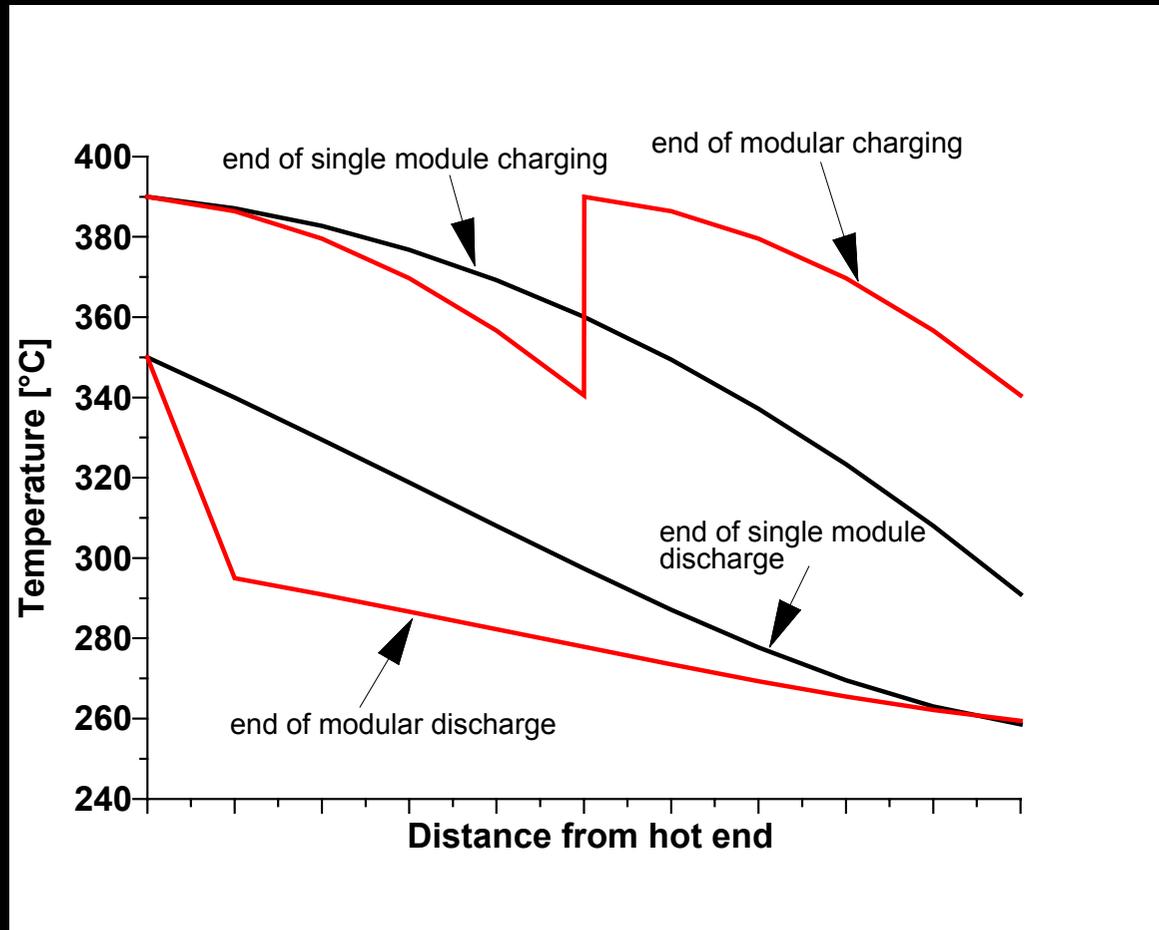


Temperature profile of the storage material after end of discharging

Maximum absorber inlet temperature determines the maximum storage outlet temperature

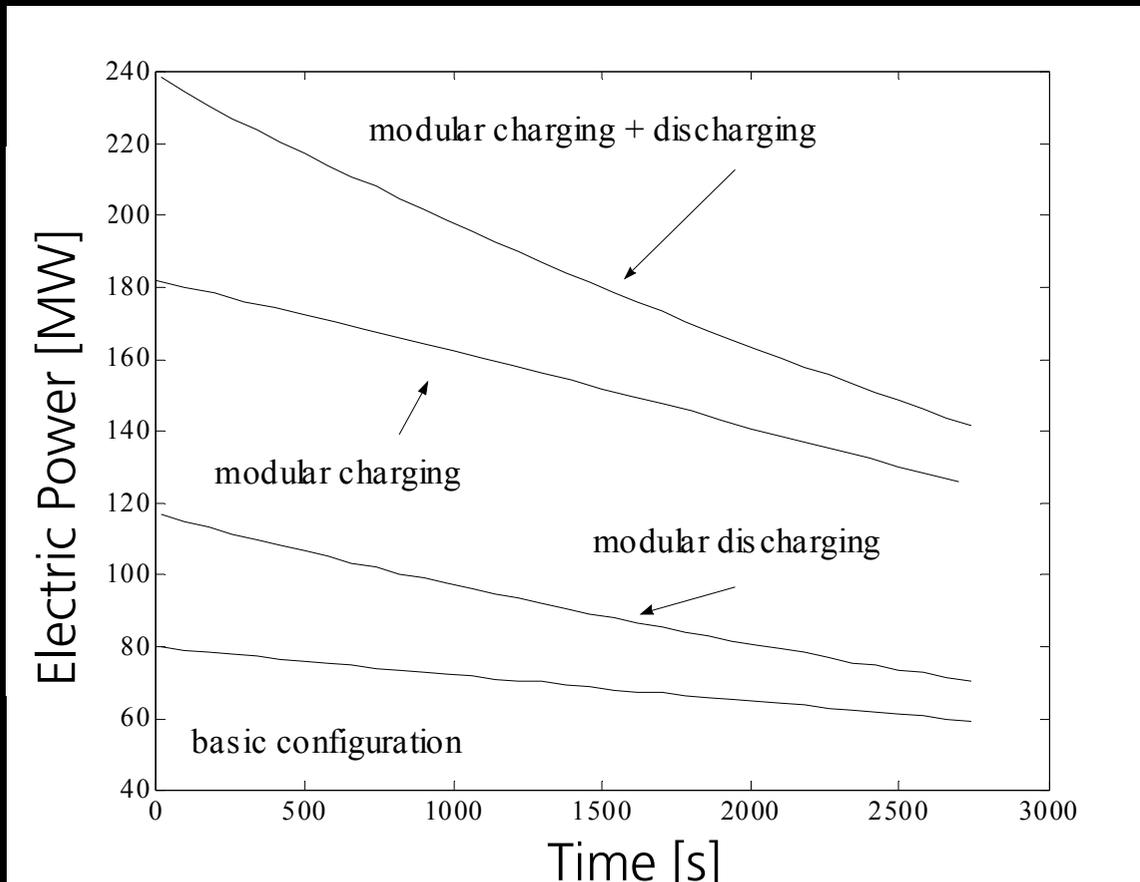


Combination of modular charging and discharging concept





Simulation Results for Modular Integration Approach



Electric Power provided during discharge for different charging and discharging strategies

Identical storage geometry!



Conclusions

- Preliminary results with concrete and ceramic based TES materials are very promising
- Design of WESPE 350 kWh test modules completed
- Manufacturing of test modules within planned schedule
- Preliminary cost figures are in the cost target
- Modular design and charging/discharging concept shows significant potential for cost reduction



Outlook

- Detail cost analysis after completion of module manufacturing and testing**
- Verification of physical and dynamic numerical simulation to optimize the design as well as operation strategies**
- Development of control strategies for modular storage concepts**
- Final decision of the TES material: Concrete or castable ceramic**
- Scale-up to multi MWh capacity pilot storage**